RADCOM TECHNICAL FEATURE

Filters and Ferrites in EMC

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THIS ARTICLE IS about the characteristics and use of various filters and ferrites for solving amateur radio EMC (Electromagnetic Compatibility) problems involving breakthrough of amateur signals into domestic equipment, such as television sets, video recorders, stereo systems etc.

This subject is covered in much greater depth together with many other important aspects of EMC for radio amateurs in the RSGB book, *The Radio Amateur's Guide to EMC*, by Robin Page-Jones, G3JWI. The book includes a comprehensive section on filters and ferrites written by myself with equivalent circuits, response curves and test methods. Various aspects of EMC have also been covered in *RadCom* and elsewhere, see [1] to [7].

INTERFERENCE OR BREAKTHROUGH?

IF YOUR TRANSMISSIONS affects broadcast radio or TV, it is important to find out whether the problem is caused by your transmitter producing unwanted signals in a radio or TV broadcast band. To cure this sort of interference, it is necessary to deal with the source of the unwanted signals, that is, the transmitter, not the receiver! Filtering at the transmitter output may be required and this subject is dealt with in [1].

If your transmitter is not at fault, then the problem is generally known as 'breakthrough', as it's caused by domestic equipment receiving strong amateur signals which it is not designed to receive. In the case of breakthrough on TV or radio broadcasts, all channels may be affected, while in other cases, (eg audio amplifiers), the equipment should not receive radio signals at all.

In a TV or broadcast radio, the first thing to check is that it is correctly tuned and that its aerial connections are in good order. In all cases of breakthrough it's important to make sure that the way your station is configured is not contributing to the problem. Where the breakthrough is not too severe, it can sometimes be cured by changes to the type or location of transmitting antenna system or, in the case of HF, the radio frequency grounding arrangements. These topics are covered in ref [2] and [3]. A small reduction in power may also solve some cases.

On each of these occasions, it is vitally important to remember that the root cause of the problem is the poor immunity of the TV or broadcast radio to strong out-of-band signals. If the breakthrough is still not cured, then you will need to add some filtering to the affected equipment.

There is, of course, a limit to the signal strength which the most immune TV can tolerate, even with filters fitted. Running the full legal power into a high gain antenna system close to neighbours' domestic equipment could exceed this limit!

HIGH PASS AND BAND STOP FILTERS

WHERE AMATEUR SIGNALS are getting into a TV, video recorder or FM broadcast receiver via its coaxial antenna cable, this can happen in two ways. The first is where amateur signals are picked up by the radio or TV antenna itself and fed down the coaxial cable in the normal way. These signals are sometimes referred to as being 'on the inner' of the cable but are more accurately known as 'differential mode' signals. They can be reduced by means of a high pass filter (HPF)which lets through the wanted broadcast signal but attenuates (reduces) amateur signals on lower frequencies. Another type of filter which may be used is a band stop or notch filter, which attenuates one particular amateur band only.

'BRAID BREAKERS'

THE SECOND WAY IN which amateur signals may be picked up is commonly referred to as 'on the braid' of a coaxial cable although this type of signal is more correctly known as a 'common mode' signal. For these signals, a

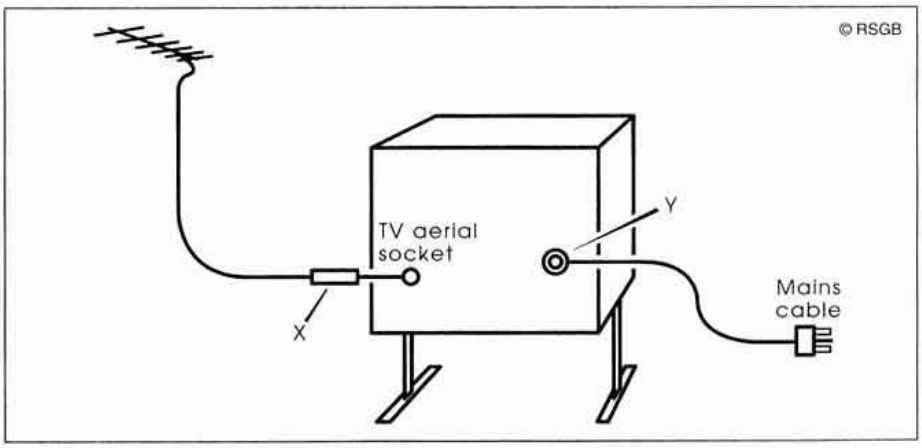

Fig 1: Fitting filters to a TV set alone.

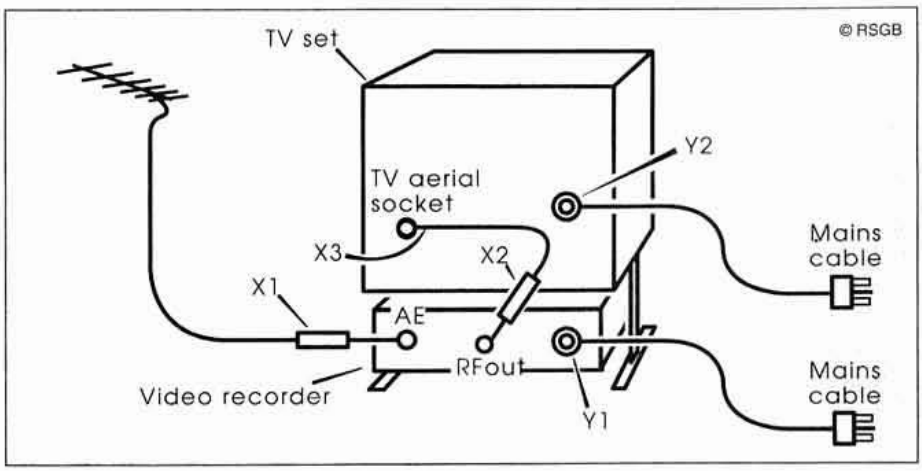

Fig 2: Fitting filters to a TV set with video recorder.

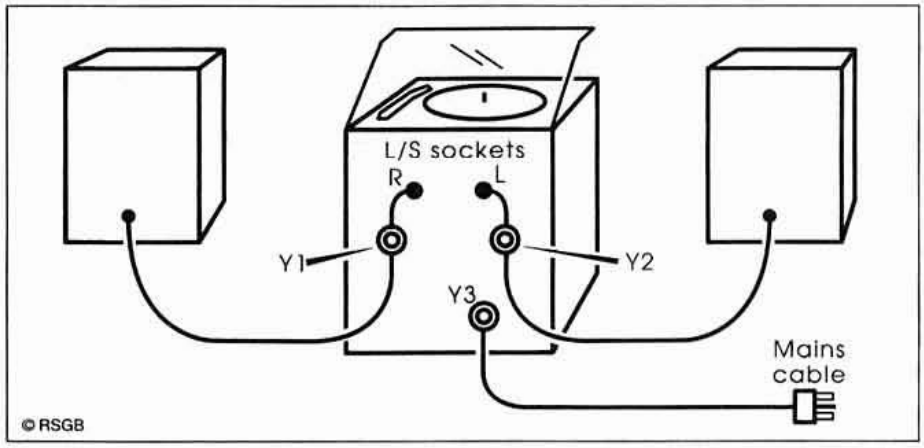

Fig 3: Fitting common mode chokes to a stereo system.

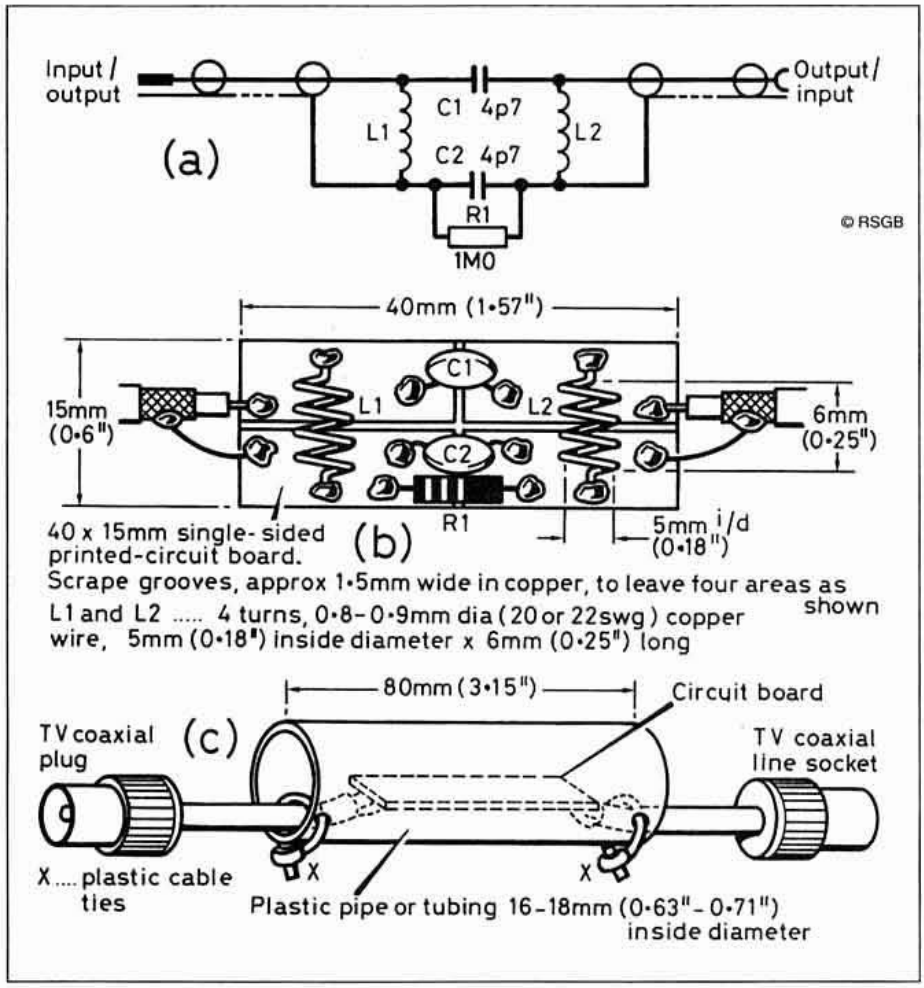

Fig 4: Home constructed high pass filter and braid breaker. (a) circuit diagram, (b) layout, (c) housing.

filter with so-called 'braid breaking' action is required. The simplest way of achieving this is by means of small value capacitors in series with both the braid and the inner. A more effective type of braid breaker is a 1:1 transformer as used in the AKD BB1 and HPFS filters.

A third type is a common mode choke type of braid breaker where a coaxial cable is wound into a coil, often on a ferrite ring or rod core. The common mode choke has the advantage of virtually zero loss for the wanted differential mode signal and it can also be used on any type of cable which is picking up amateur signals, not only coaxial cables but also audio cables, mains cables etc.

WHERE TO FIT FILTERS

SUITABLE LOCATIONS FOR filters on a TV set without a video recorder, are shown in **Fig 1**. 'X' represents a filter and/or braid breaker in the coaxial antenna cable and this is often all that is required, especially at HF. In some cases it is better to fit the filter 0.5 to 2 metres away from the TV set, for example at a coaxial wall socket (the filters are bi-directional so it does not matter which is the input and which is the output)

If this does not cure the problem, then a common mode choke 'Y' may also be required on the mains lead. Keeping this 0.5-2 metres away from the TV set may make it more effective at HF. To avoid the need to remove mains plugs (especially if moulded on!), a short mains extension cable can be made up with the cable wound on a suitable ferrite core.

Fig 2 shows where to fit filters to a TV with a video recorder. A filter and/or braid breaker should be fitted in the coaxial cable at 'X1' and if this is not sufficient, another should be fitted at 'X2' or 'X3'. Further filtering may be required, such as common mode chokes on the mains cables at 'Y1' and/or at 'Y2'.

In cases where an indoor pre-amplifier is used, it will generally be necessary to fit a filter at its input(s), and sometimes also at its output(s). A common mode choke may also be required on its mains lead.

In the case of breakthrough into the audio amplifier of a stereo system, common mode chokes should be fitted near the speaker sockets as shown by 'Y1' and 'Y2' in **Fig 3**. For ease of fitting, two short speaker extension cables can be made up, each with its cable wound on a separate ferrite core. In some cases, common mode chokes may also be required on other cables such as at 'Y3' on the mains cable.

Fig 4 shows a high pass filter suitable for home construction.

REFERENCES

[1] Is Your Own House in Order? G L Benbow, G3HB, *RadCom*, Jan 1991.

[2] Breakthrough, *RSGB Amateur Radio Call Book*.

[3] EMC – Dealing with Interference, RSGB Amateur Radio Call Book, 1994 edition.

[4] Diagnosis of a Problem, R Page-Jones, G3JWI, *RadCom*, Sept 1990

[5] EMC Standards and Regulations, R Hewes, G3TDR, and A Dearlove, G1WZZ, *RadCom*, July 1990

[6] Were You on Your Radio Last Night? (Parts 1 & 2), A McKenzie, G3OSS, *RadCom*, May/June 1987

[7] *Radio Amateur's Examination Manual*, 12th Editions, G Benbow, G3HB, and *RSGB Handbook*, Chapter 8, 'Electromagnetic Compatibility'.

NEXT MONTH

IN PART TWO, David Lauder describes the characteristics of several practical filters.

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THE CHARACTERISTICS given in **Fig 5** and **Table 1** were obtained from measurements made by the author except for the TNF2 range where the manufacturer's figures are quoted. In many cases, the measured performance of a typical filter is significantly better than the manufacturer's figures. Full details of test methods and response curves are given in [8].

For each filter, the performance on various amateur bands is shown by bar graphs to the nearest 5dB. One square represents 10dB and a half square represents 5dB. 'Differential mode loss' shows how good each filter is at rejecting amateur signals 'on the inner' while 'common mode loss' shows how good the 'braid breaking' is (if any). A loss of 10dB may cure minor breakthrough but in most cases 20dB, 30dB or more may be required. Six squares with a '+' represents more than 60dB.

All the filters described have a pass band which includes the UHF TV band (Bands 4 and 5: 470-860MHz) but the only filters which also pass the FM broadcast band (Band 2: 87.5-108MHz) are the AKD HPF2 and the BB1 braid breaker. The ferrite-cored common mode chokes pass differential mode signals at all frequencies.

Ideally, a filter would have no loss in the pass band but all practical filters do have a measurable pass band loss which may vary in different parts of the pass band. Where the UHF TV signal strength is high, a loss of 3-5dB may not be noticeable but if the signal is weak then even a 2dB loss could give a slight but noticeable increase in noise on the picture. Some types of filter can affect Teletext reception even although there may be no visible effect on the picture. With a Teletext TV, it is wise to check that Teletext reception is unaffected after fitting a filter.

Listed in Table 1 are a number of filters which can prove most effective for a variety of EMC problems. Where an RSGB description is given, the filter is available from RSGB Sales - see *Book Case* pages (94 and 95) for ordering details.

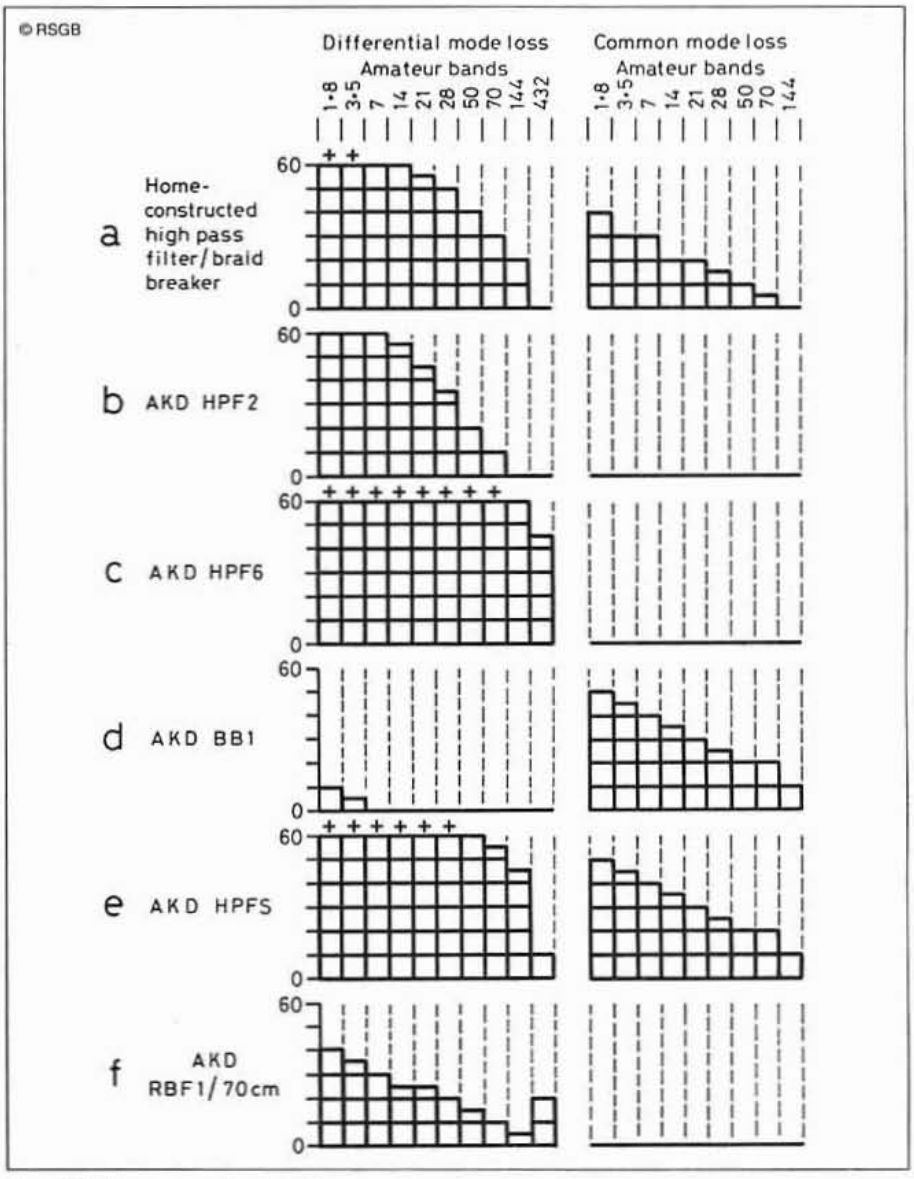

Fig 5: Filter losses on various bands.

FERRITE-CORED COMMON MODE CHOKES

VARIOUS TYPES OF ferrite ring cores (toroids), split cores or rods can be used to make common mode chokes on coaxial cables, mains cables, audio cables etc. These chokes reduce unwanted common mode signals picked up from a transmitter but any differential mode signals in the cable, whether wanted or unwanted, pass through with negligible loss. Common mode chokes can also be used to reduce interference from computer cables, etc.

To be effective, a common mode choke needs to present a high enough impedance at the frequency of operation and should preferably be lossy. This requires a suitable grade of ferrite; surplus cores of unknown type may not be suitable. At HF, 10 or more turns may be required while above 10MHz and particularly at VHF, it is important to minimise coupling between the two ends of the winding. It is recommended that ring cores should always be wound with a split winding as shown in **Fig 6**. When using this winding method, it is vital that the cable always goes through the

Home constructed high pass filter and braid breaker.

Type:	Balanced L-C high pass filter (UHF TV) with capacitive braid breaking.
Pass band:	Bands 4 and 5 (UHF TV).
Loss in pass band:	Typically 0.5 to 2dB.
Stop band performance:	See **Fig 6a**
Remarks:	This filter has good rejection of HF differential mode signals although rejection of common mode signals is not as good as a transformer type braid breaker. It is only moderately effective at 144MHz. The construction details are given in **Fig 4** and are based on ref [7] (see part one).

AKD HPF 1 High pass filter and braid breaker.

Type:	L-C High pass filter (UHF TV) with capacitive braid breaker.
Pass band:	Bands 4 and 5 (UHF TV)
Loss in pass band:	Typically 0.5 to 2dB.
Remarks:	The HPF1 has similar performance to the home constructed filter above but has slightly better stopband performance. It is not available from RSGB except as part of the RFK1 filter kit.

AKD HPF 2 High pass filter.

RSGB description:	Filter 2 - High pass for FM Broadcast Band 2.
Type:	L-C High pass filter (FM Broadcast) without braid breaking.
Pass band:	Bands 2 (FM radio broadcast), up to 4 and 5 (UHF TV)
Loss in pass band:	Typically less than 1dB in most of Band 2 (2.5dB at 87.5MHz), 1 to 3dB in Bands 4 and 5.
Stop band performance:	See **Fig 6b**.
Remarks:	The HPF2 is intended for reducing breakthrough on FM broadcast receivers (87.5 - 108MHz), particularly from HF signals but it is also useful for rejecting 50MHz signals. It is only effective against differential mode signals as it has no braid breaking action.

AKD HPF 6 High pass filter

RSGB description:	Filter 8, six section for UHF TV.
Type:	Equivalent to 6 section L-C High pass filter (UHF TV), sharp cut-off, without braid breaking.
Pass band:	Bands 4, 5 (UHF TV).
Loss in pass band:	Typically 1-3dB (Channels 21-40), 1-2dB (Channels 41-68).
Stop band performance:	See **Fig 6c**.
Remarks:	The HPF6 is a high performance high pass filter with a very sharp cut off below 470MHz. This is by far the most effective filter for reducing breakthrough from the 430-440MHz amateur band and is also very effective on all bands below 430MHz. If a UHF TV mast head pre-amp is in use, the HPF6 should be fitted on the input side of the pre-amp, either by mounting it in a weatherproof box at the mast head or by putting the filter and pre-amp in a loft close to the TV antenna.

AKD BB1 Braid breaker

RSGB description:	Filter 1, Braid breaker.
Type:	1:1 transformer type braid breaker only.
Pass band:	Below 10MHz to over 1 GHz
Loss in pass band:	Typically 2dB over most of its range but, 3 to 4dB at UHF channels 50 - 68.
Stop band performance:	See **Fig 6d**.
Remarks:	The BB1 is more effective against common mode signals picked up 'on the braid' than a capacitive braid breaker such as HPF1. The BB1 is particularly effective at HF although the braid breaking action diminishes at VHF due to interwinding capacitance of the transformer. A BB1 can be cascaded with other filters such as HPF2 or HPF6 which do not have any braid breaking action, although this increases the total passband loss.

AKD HPFS High pass filter (special)

RSGB description:	Filter 3, High pass for UHF TV.
Type:	L-C high pass filter with transformer type braid breaker.
Pass band:	Bands 4, 5 (UHF TV).
Loss in pass band:	Typically 3-4dB (Channels 21-40), 4-5dB (Channels 41-68).
Stop band performance:	See **Fig 6e**.
Remarks:	The HPFS is a BB1 and high pass filter combined. It has very effective rejection of differential mode signals on the 144MHz band and below. Due to the relatively high pass-band loss, it is not suitable for areas where the TV signal strength is low.

AKD RBF1/70 cm notch filter.

RSGB description:	Filter 5, notch tuned to 435MHz
Type:	Series resonant trap between inner conductor and braid. No braid breaking.
Pass band:	Bands 4, 5 (UHF TV).
Loss in pass band:	Typically 2-5dB (Channels 21-30), 1-2dB (Channels 31-68).
Stop band performance:	See **Fig 6f**.

The RBF1/70cm is pretuned to 435MHz but is not as effective as an HPF6 on the 70cm band. The RBF1/70cm also has a high pass action with useful rejection of HF differential mode signals.

AKD TNF2 tuned notch filter range.

AKD type	RSGB Description
TNF2/145MHz	Filter 4, notch tuned to 145MHz
TNF2/70MHz	Filter 7, notch tuned to 70MHz
TNF2/50MHz	Filter 6, notch tuned to 50MHz
TNF2/28	Filter 10, notch tuned to 28MHz (10m)
TNF2/21	Filter 15, notch tuned to 21MHz (15m)
TNF2/14	Filter 20, notch tuned to 14MHz (20m)
Type:	L-C notch (band stop) filter in series with inner conductor and braid with resonant braid breaking action at tuned frequency only.
Pass band:	Bands 4, 5 (UHF TV).
Loss in pass band:	Typically 0.5-2dB (Channels 21-40), 2dB (Channels 41-68)
Stop band performance in the specified band (manufacturer's figures):	>35dB 'on the inner', >30dB 'on the braid'.
Remarks:	These filters provide rejection of differential mode and common mode signals in one particular amateur band only and have low pass-band loss in UHF TV bands 4 and 5. They are not suitable for passing FM broadcast Band 2 signals.

Where a UHF TV preamplifier or a distribution amplifier is used, a filter will generally be required on the input side of the amplifier. The TNF2 type of tuned notch filter is not recommended in such cases.

Table 1: Summary of filter characteristics.

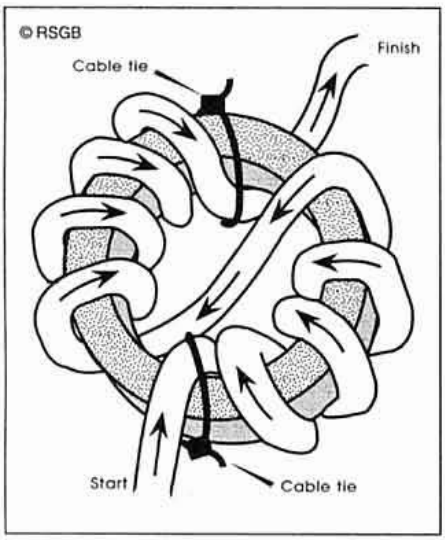

Fig 6: Recommended winding method for ferrite ring chokes.

hole in the core in the same direction as shown.

Semi-airspaced coaxial cable should not be wound onto any of the ferrite cores mentioned below as the tight bend radius may cause the cable to collapse internally and short circuit.

NEOSID FERRITE RING CORES

FOR THE 1.8 AND 3.5MHz bands, a pair of the Neosid 28-041-28 ferrite rings supplied by the RSGB (order code 'FERR') with a 14 turn winding give better performance than any of the other types of ferrite core mentioned below. The performance of such a winding is shown in **Fig 7a**. 14 turns on a pair of these rings still gives useful performance up to and including the 28MHz band. If the cable is too thick to allow 14 turns, then more rings are required to give the same effect. For maximum effectiveness with these Neosid rings on the HF bands, the number of turns squared multiplied by the number of rings should equal about 400 although 200 may be enough at 21MHz and above. This means that if the number of turns is halved, then four times as many rings are required to give the same effect.

At 50MHz, 7 or 14 turns give similar results while at 70MHz and above, a seven turn winding is recommended. At 144MHz, seven turns on one ring gives almost identical results to seven turns on two rings. For the performance of seven turns on a pair of rings, see **Fig 7b**. If wound with coaxial cable, the resulting common mode choke can be more effective than a BB1 braid breaker at 145MHz but with negligible insertion loss to all differential mode signals (such loss is only the loss in the length of coaxial cable wound through the ring and the loss in any additional coaxial connectors.) If more than about 10 turns of coax are required, a short length of miniature 75Ω coax cable will be required, such as miniature RG59 or RG179B/U. The loss in one metre of such miniature cable is less than 1dB even at the top of the UHF television band.

PHILIPS FERRITE RING CORES

A 12 TURN WINDING on a single Philips Components ring core type 4330-030-34450 gives good performance at 3.5 and 50MHz and very good performance from 7 - 28MHz, as shown in **Fig 7c**. In some cases, an 8 turn winding may be sufficient. One of these rings is wider than a pair of Neosid 28-041-28 rings but has a slightly smaller aperture (23mm instead of 25mm). It has a bright pink coating to indicate the grade of ferrite (4A11). Another useful type of Philips ring core is the 4332-020-97200 which has a violet coating and is made of 4C65 grade ferrite. The characteristics of a 12 turn winding on such a core are shown in **Fig 7d**. It has better performance than the 4A11 grade core at around 21MHz

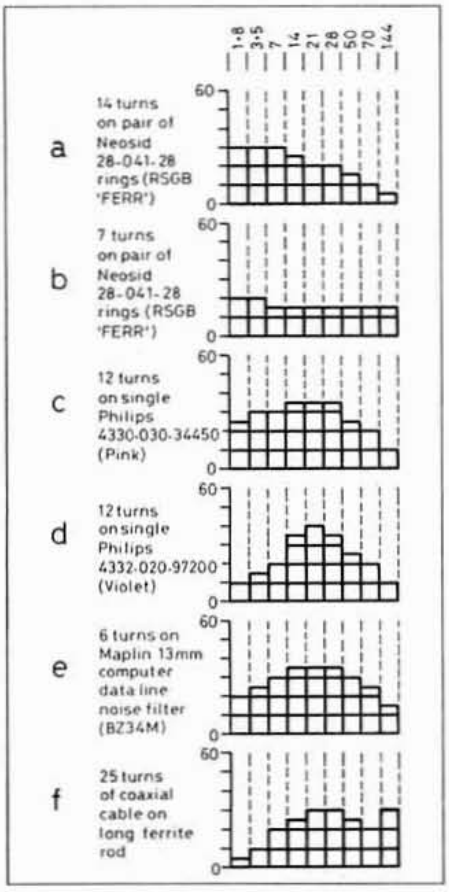

Fig 7: Ferrite-cored common mode choke losses .

but is significantly poorer at 7MHz and below due to its lower permeability.

The two Philips ring cores mentioned above are available through Philips Components trade distributors such as Hawnt Electronics Ltd. The 4C65 grade cores are more expensive than the 4A11 grade but may be more easily available.

CLIP-ON CHOKES.

A USEFUL TYPE OF clip-on choke can be found in the computers section of the Maplin Electronics catalogue and is called a computer data line noise filter (Stock No BZ34M). This is a split ferrite bead with a 13mm diameter hole which can be fitted on to a cable without the need to remove connectors. For amateur radio EMC purposes six turns are recommended and this will only be possible with fairly thin cables such as some loudspeaker, telephone or alarm cables. The characteristics of a six turn winding on a Maplin type BZ34M are shown in **Fig 7e**.

FERRITE RODS.

A MW/LW FERRITE AERIAL rod can be used to make an effective, if somewhat large, common mode choke for the higher HF bands and for VHF. A 200 x 9.5mm ferrite rod with 25 turns is fairly effective at frequencies of 14MHz and above. Ferrite rods also make effective common mode chokes at VHF because the ends of the winding can be well separated. At 145MHz, a 10 turn winding may be used on a rod 140mm long and gives better results than any of the ring cores or split cores mentioned above. A 25 turn winding on a 200mm long rod turns generally gives better results than 10 turns but requires about 1.2 metres of spare cable. **Fig 7f** shows the performance of 25 turns on a long ferrite rod.

REFERENCE

[8] *The Radio Amateur's Guide to EMC*, Appendix 3, Robin Page-Jones, G3JWI. Published by RSGB.